IR design and critical machine parameters for detector design and simulation (Stage I): JLab MEIC

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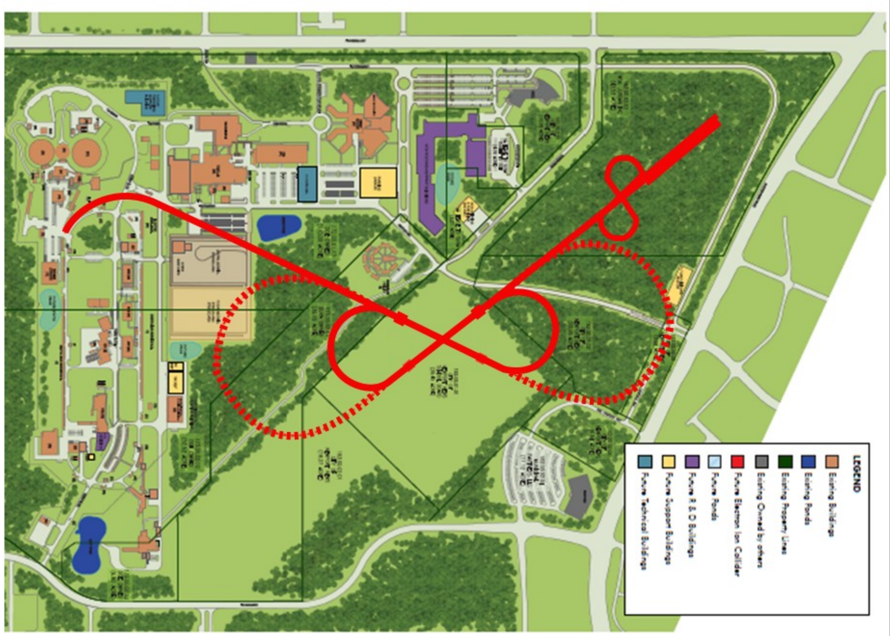
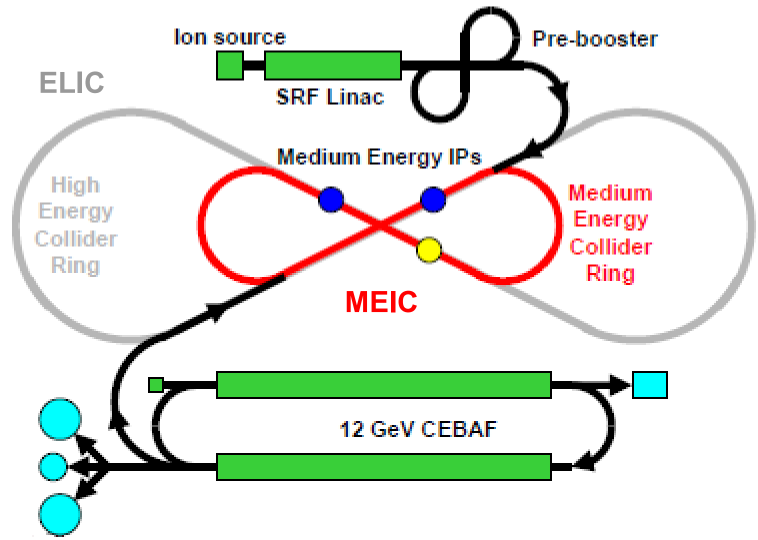
Generic Detector R&D for an Electron Ion Collider
Advisory Committee Meeting, BNL, May 17, 2012

The EIC at JLab – overview



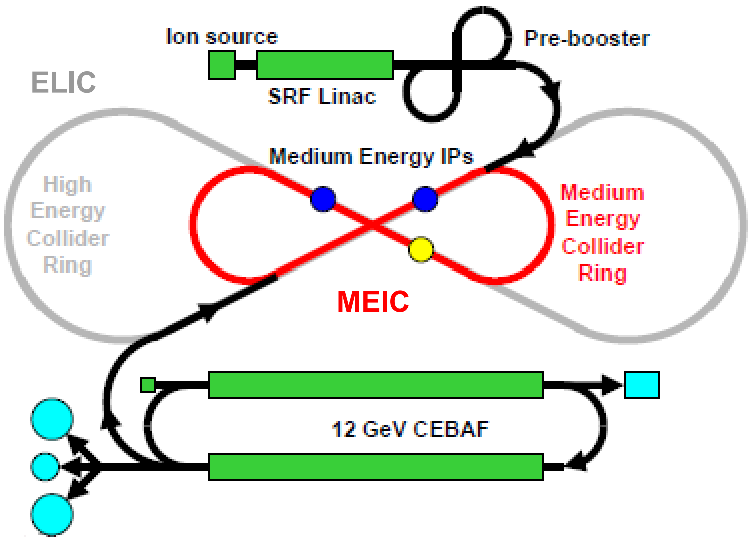


- Stage I (MEIC):
  - 3-11 GeV electrons on 20-100 GeV protons (12-40 GeV/A heavy ions)
  - About the same size as the 12 GeV CEBAF accelerator (1/3 of RHIC)
- Stage II (ELIC):
  - 20 GeV electrons on 250+ GeV protons (100+ GeV/A heavy ions)

MEIC – a figure-8 ring-ring collider

The design makes possible:

- Simultaneous use of multiple detectors
- Longitudinal and *transverse* polarization of light ions
  - protons, ***deuterium***, ^{3}He, ...
- Longitudinally polarized leptons
  - electrons and ***positrons***
- Running fixed-target experiments in parallel with collider

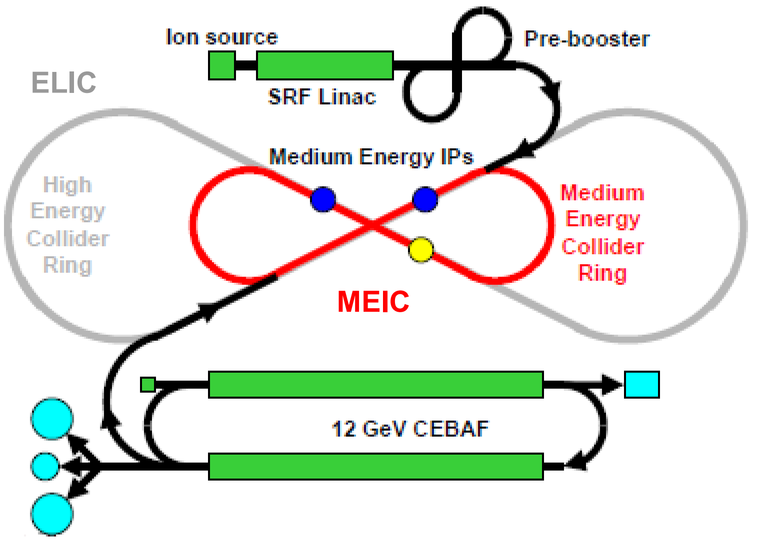


- Reduced R&D challenges
  - Regular electron cooling
    - Affects beam size (σ)
  - Regular electron source
  - No multi-pass ERL

MEIC – detectors and Interaction Regions (IR)

Space for 3 Interaction Points (IP)

- Main IPs located close to outgoing ion arc to reduce backgrounds



Full-acceptance detector (primary)

- 7 m from IP to ion final-focus quads
- *Focus of this presentation*

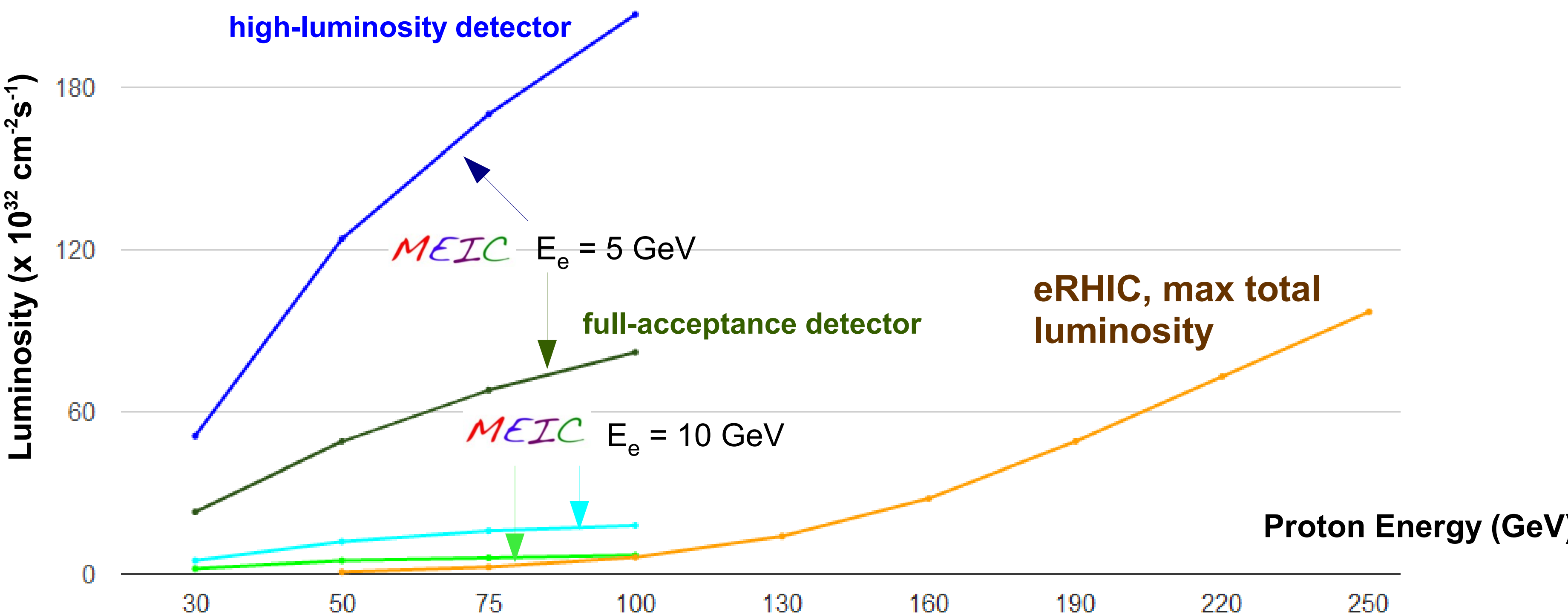
Special IP

- Space reserved for future needs

High-luminosity detector (secondary)

- 4.5 m from IP to ion final-focus quads
  - Same as in BNL design

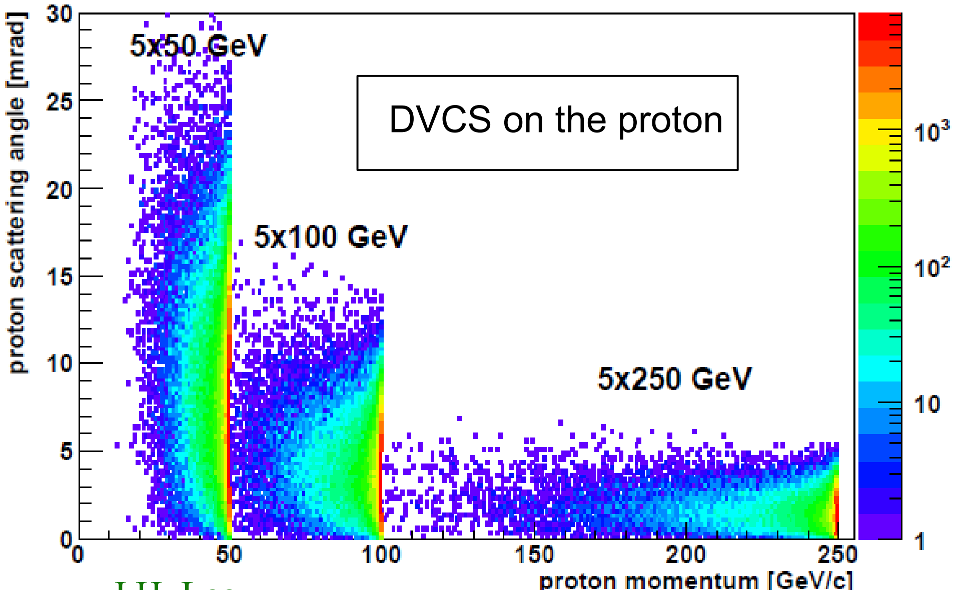
Luminosity as a function of proton energy



- MEIC luminosity is optimized for mid-range (4-8 GeV) electron energies over a wide range of proton energies.
  - Luminosities are listed *per detector*. All can be used simultaneously.

- eRHIC offers a high luminosity at a high proton energy.
  - Luminosity is given for *all detectors*, which share the beam time.

Recoil baryons



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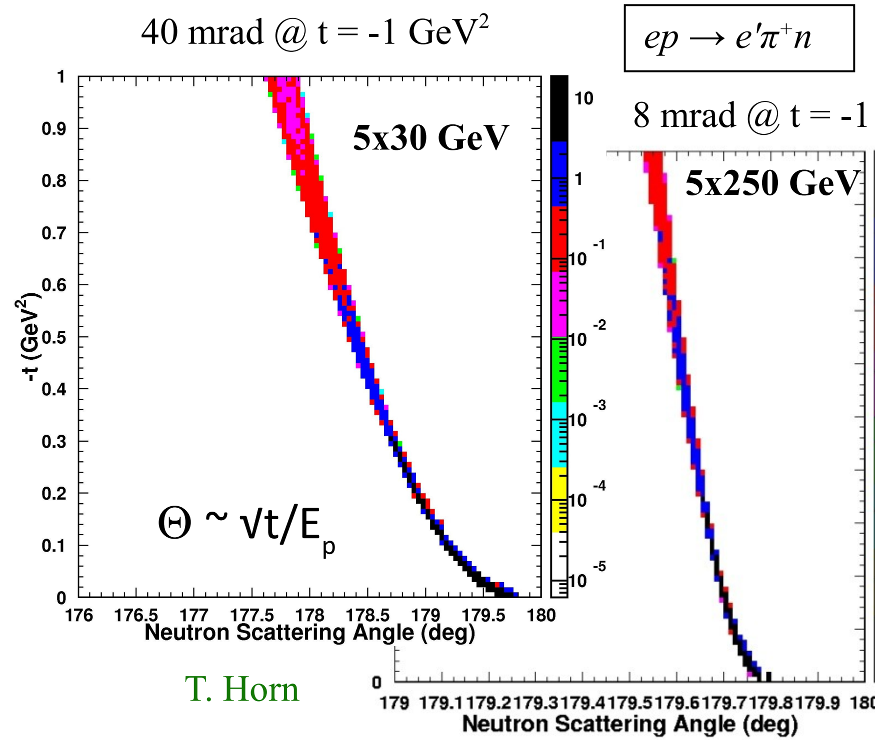
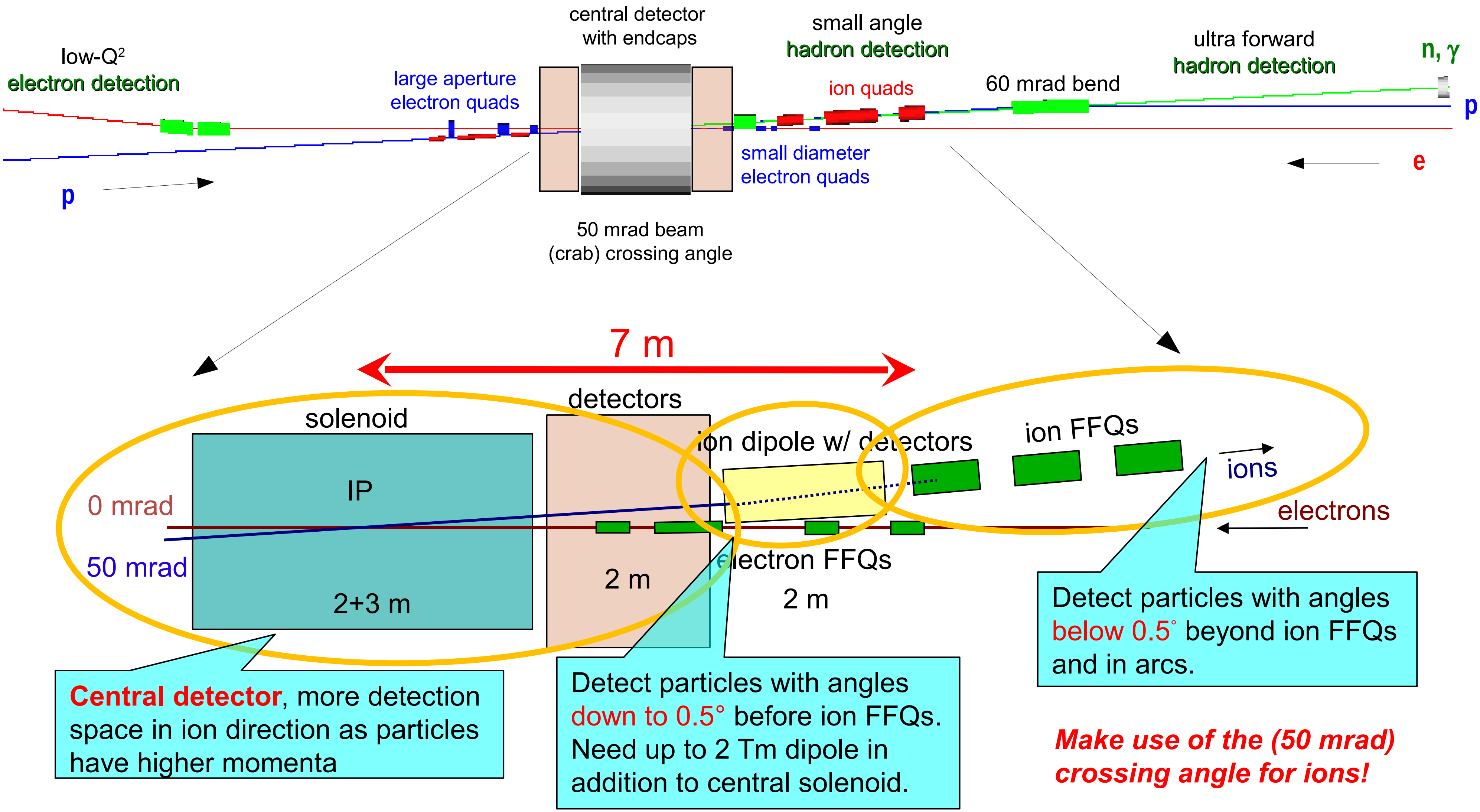


T. Horn

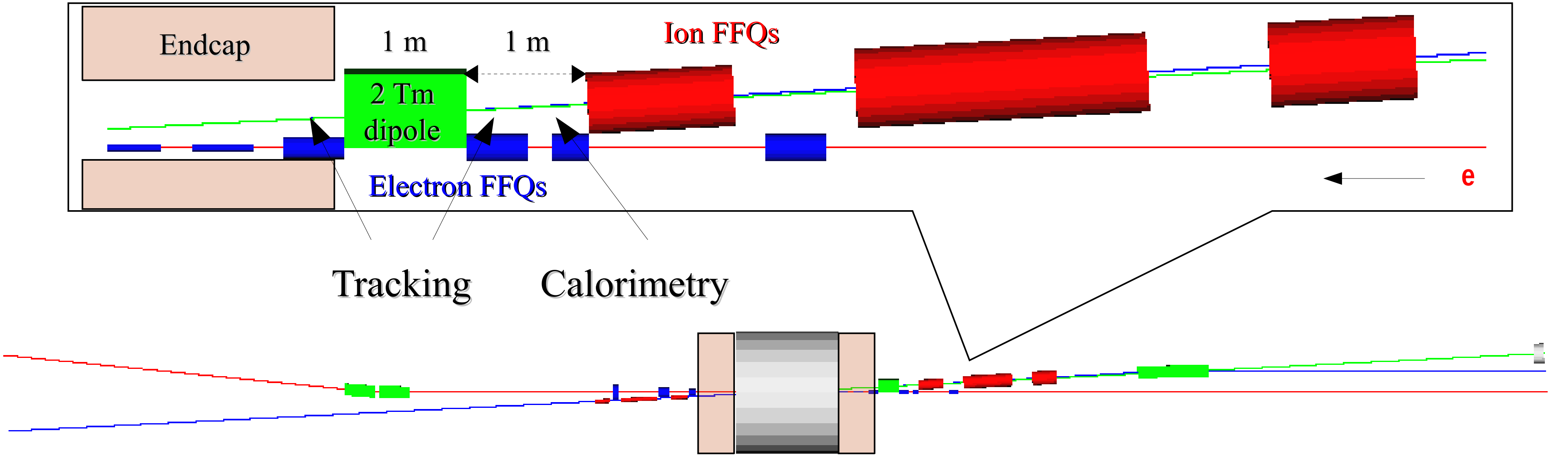
- At high proton energies, recoil baryons are scattered at small angles
  - Lower energies give better *resolution* in *-t*
- Taking full advantage of different kinematics requires
  - High luminosity over a wide range of proton (deuteron) energies
  - Excellent small-angle detection

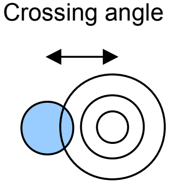
Full-acceptance detector – strategy



Make use of the (50 mrad) crossing angle for ions!

Hadron detection prior to ion FFQs





- Large crossing angle (50 mrad)
  - Moves spot of poor resolution along solenoid axis into the periphery
  - Minimizes shadow from electron FFQs
- Large-acceptance dipole further improves resolution in the few-degree range
  - Need tracking in front and behind dipole
  - Need compact calorimeter in front of ion FFQ

Detection after FFQs – requirements

1. Good acceptance for ion fragments (large dp/p)
   - Large downstream magnet apertures
   - Low downstream magnet gradients (to allow realistic peak fields)

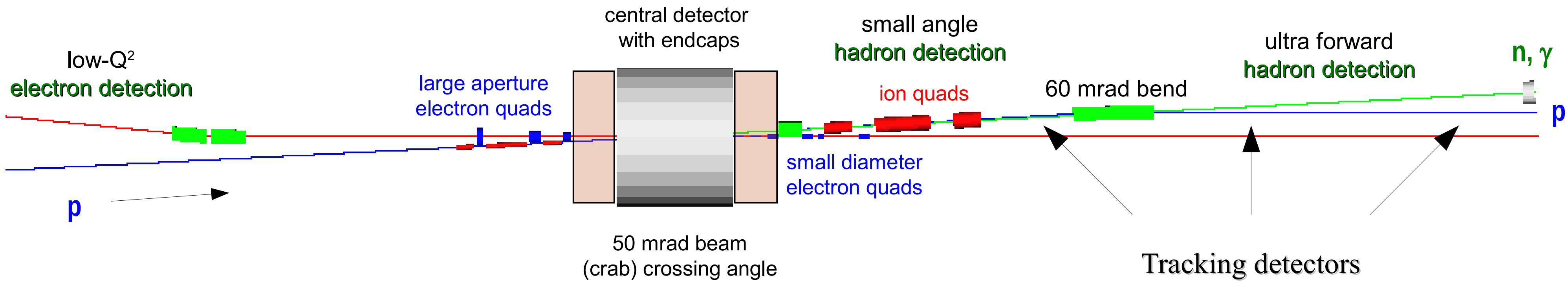
2. Good acceptance for recoil baryons (small dp/p)
   - Small beam-stay-clear at second focus (to get close to the beam)
   - Large dispersion (to separate scattered particles from the beam)

3. Good momentum- and angular resolution
   - Large dispersion (*e.g.*, 60 mrad bending dipole)
   - Long magnet-free drift space for detectors

4. Sufficient separation between beam lines (~1 m)

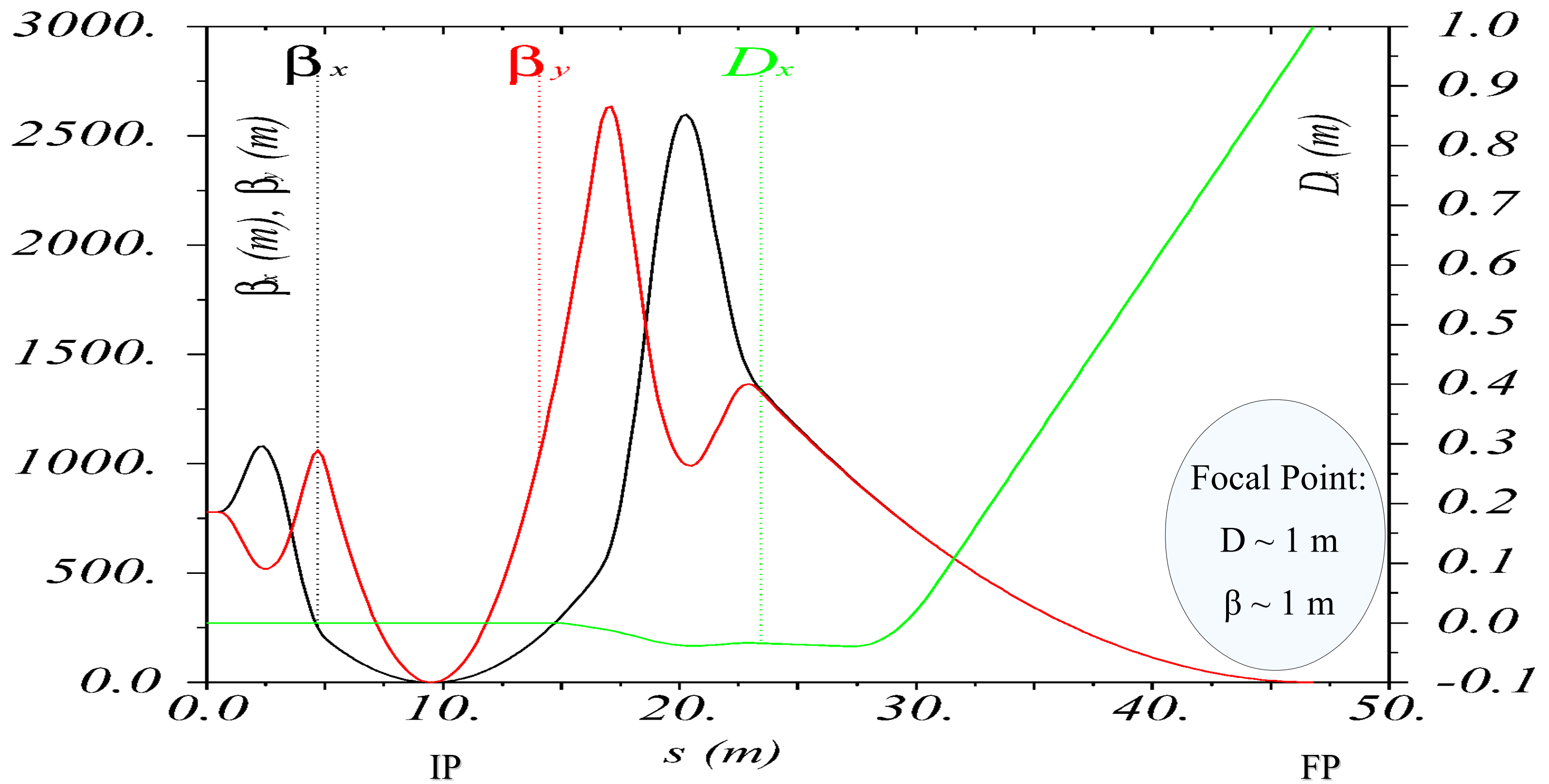
IR ion optics

No other magnets or apertures between IP and FP!

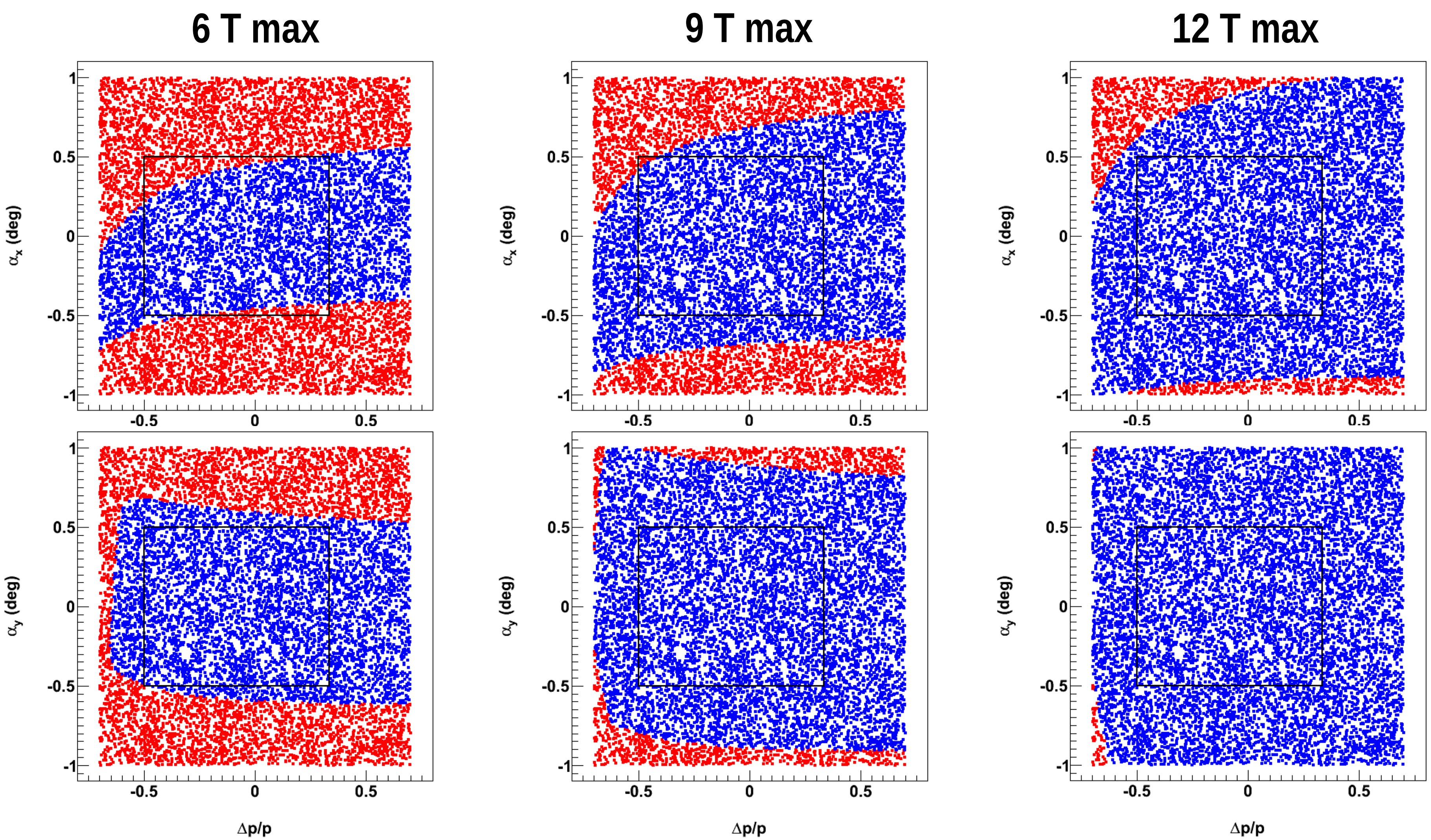


β << 1 m at FP would improve acceptance for recoil baryons but also create chromaticity in the accelerator.

For best ion fragment acceptance, downstream dipoles have opposite sign of dispersion



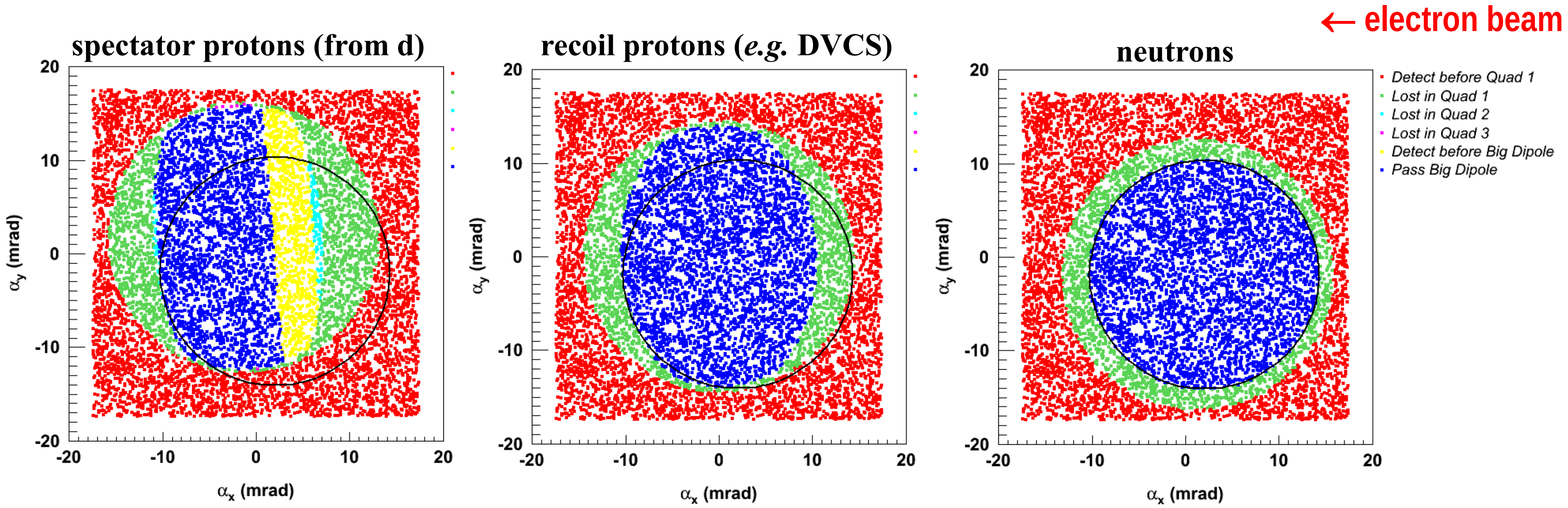
Ion acceptance – quad peak fields



Red: Detection between the 2 Tm upstream dipole and ion quadrupoles

Blue: Detection after the 20 Tm downstream dipole

Ion acceptance @ 9 T



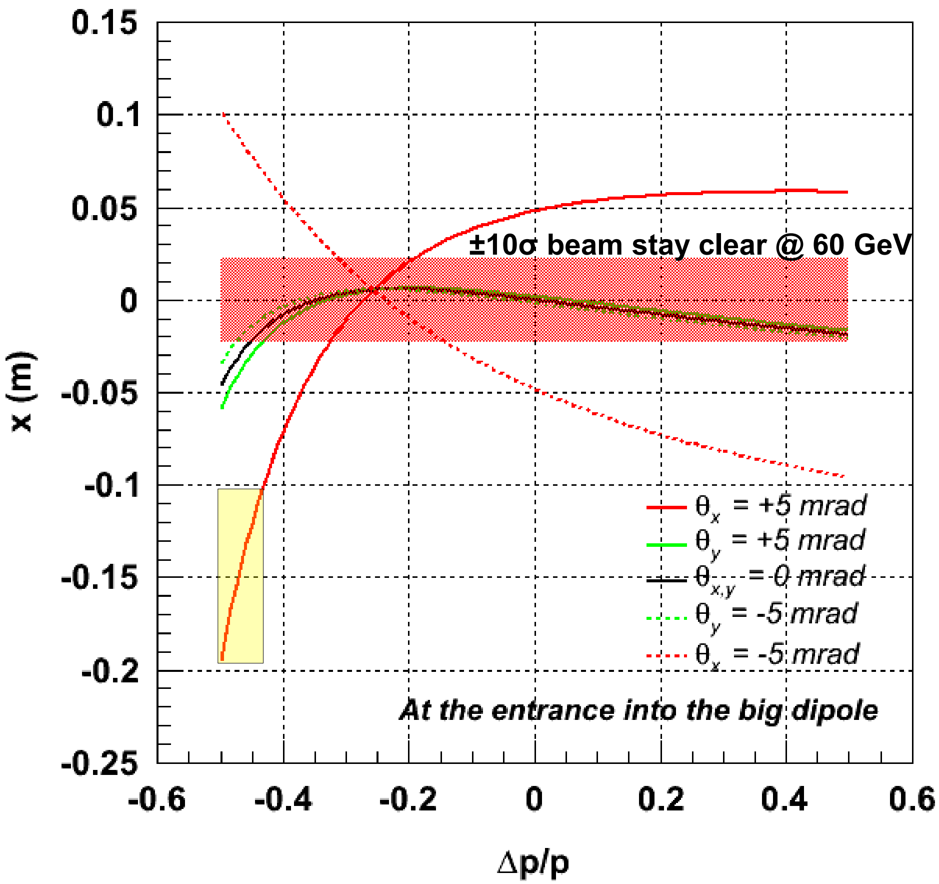
Red and Green: Detection between upstream 2 Tm dipole and ion quadrupoles

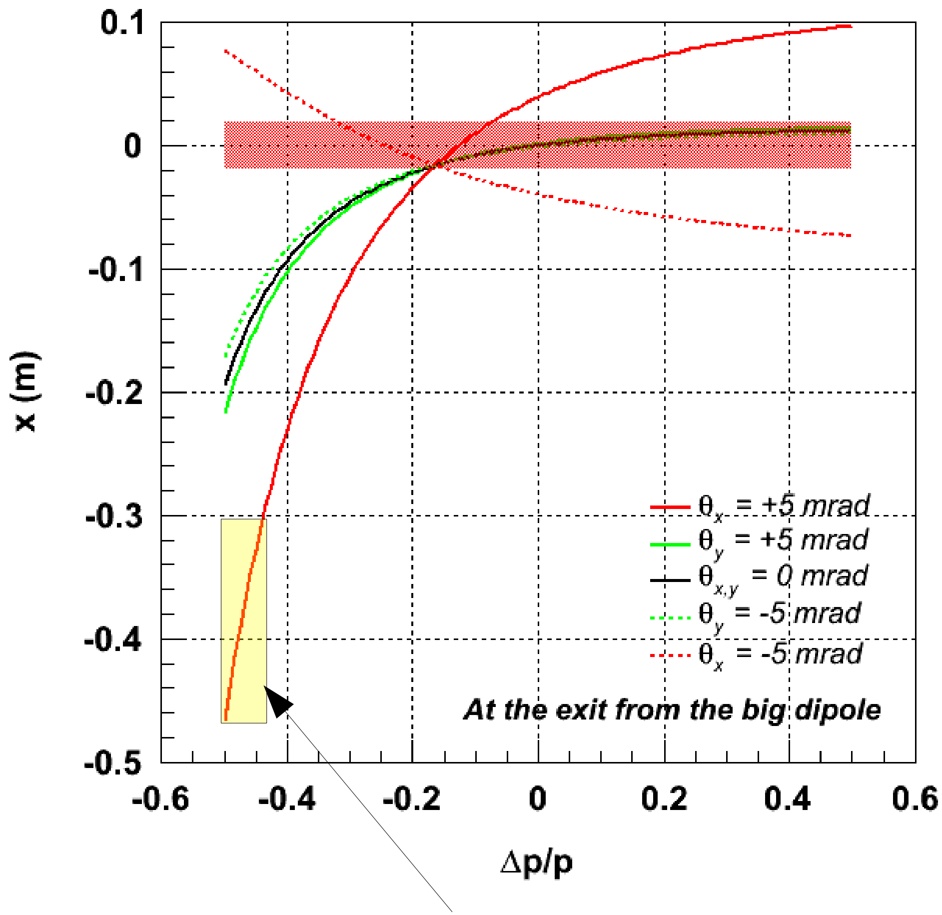
Yellow: Detection between ion quadrupoles and downstream 20 Tm dipole

Blue: Detection after the 20 Tm downstream dipole

- Reasonable ion quad peak fields at 100 GeV: 9, 9, and 7 T, respectively.
  - Can be reduced to 8, 8, and 6 T with small impact.
- Aperture of downstream dipole (blue) can be adjusted – shown shifted for illustration
- Angles shown are scattering angles at IP with respect to the ion beam direction

Ion acceptance and resolution at the 20 Tm dipole

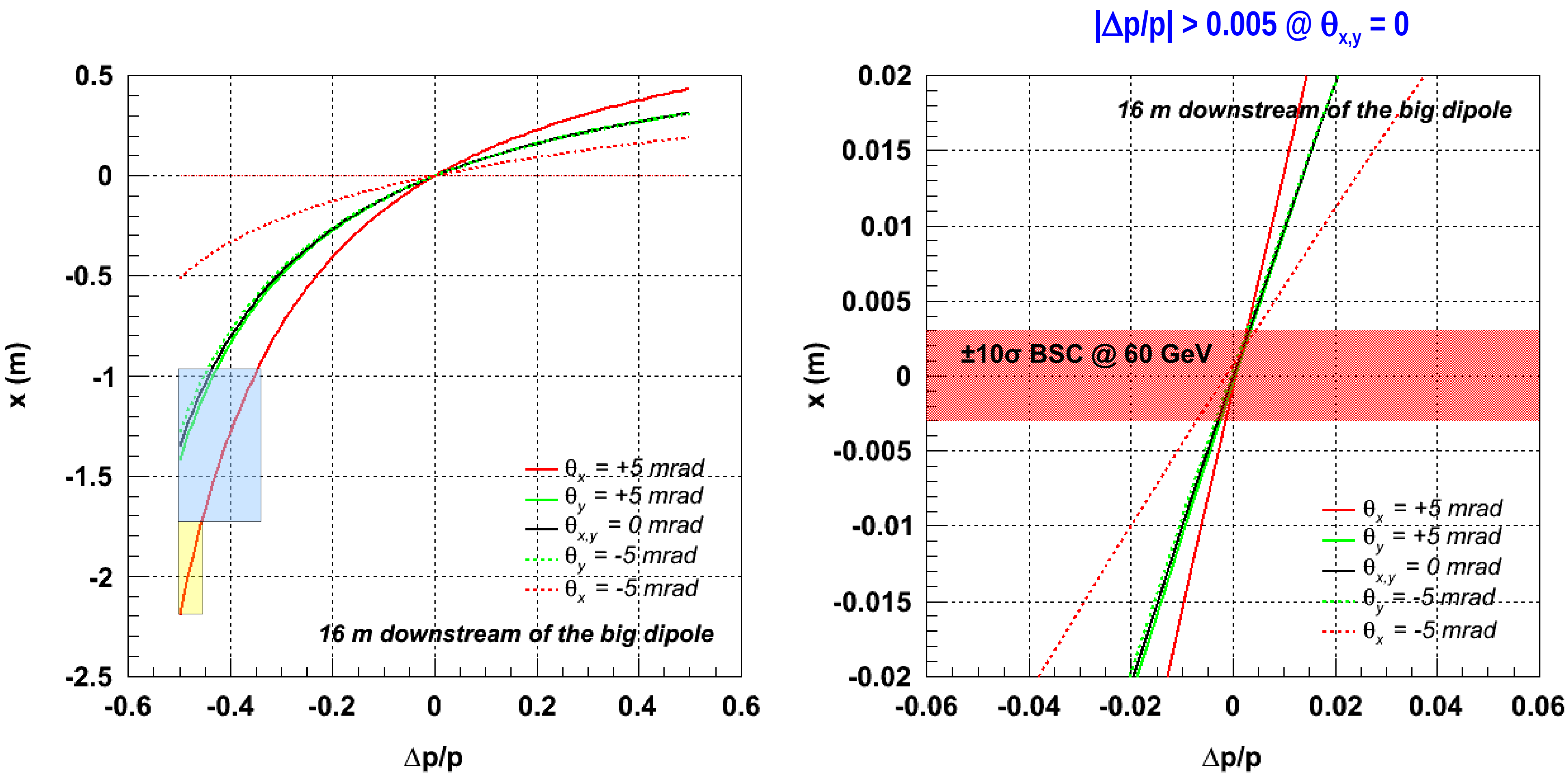




Detected only between ion quads and 20 Tm dipole

- An aperture of ± 30 cm is sufficient for all particles with $\Delta p/p > -0.45$ or $\Theta_x < +4$ mrad.
- Momentum resolution is given by the slope of the line

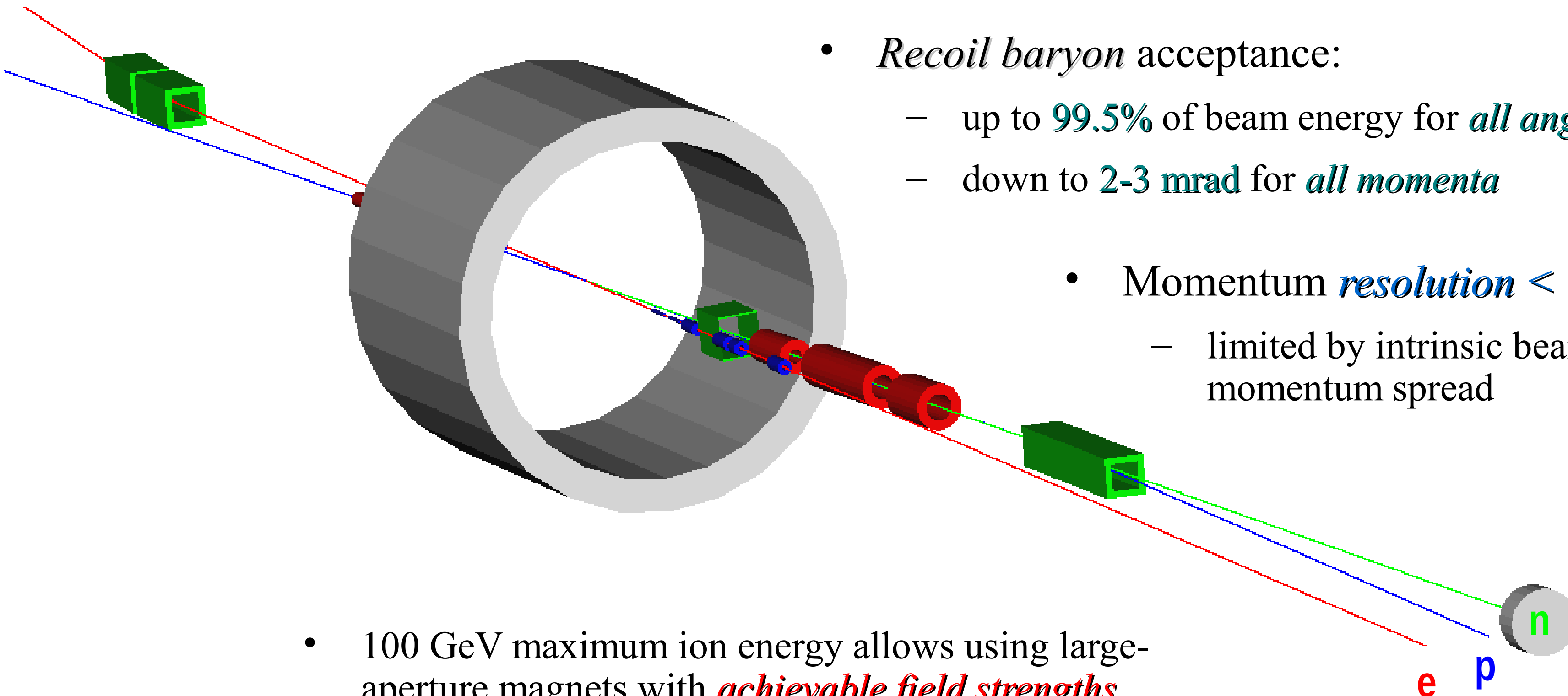
Ion acceptance and resolution at the focal point



- Recoil baryons do not gain $\Delta p/p$ (or $\Delta m/m$)
- Large deflections allow precisce tracking over long distances with cheaper detectors
  - Particles with deflections > 1 m will be detected closer to the dipole

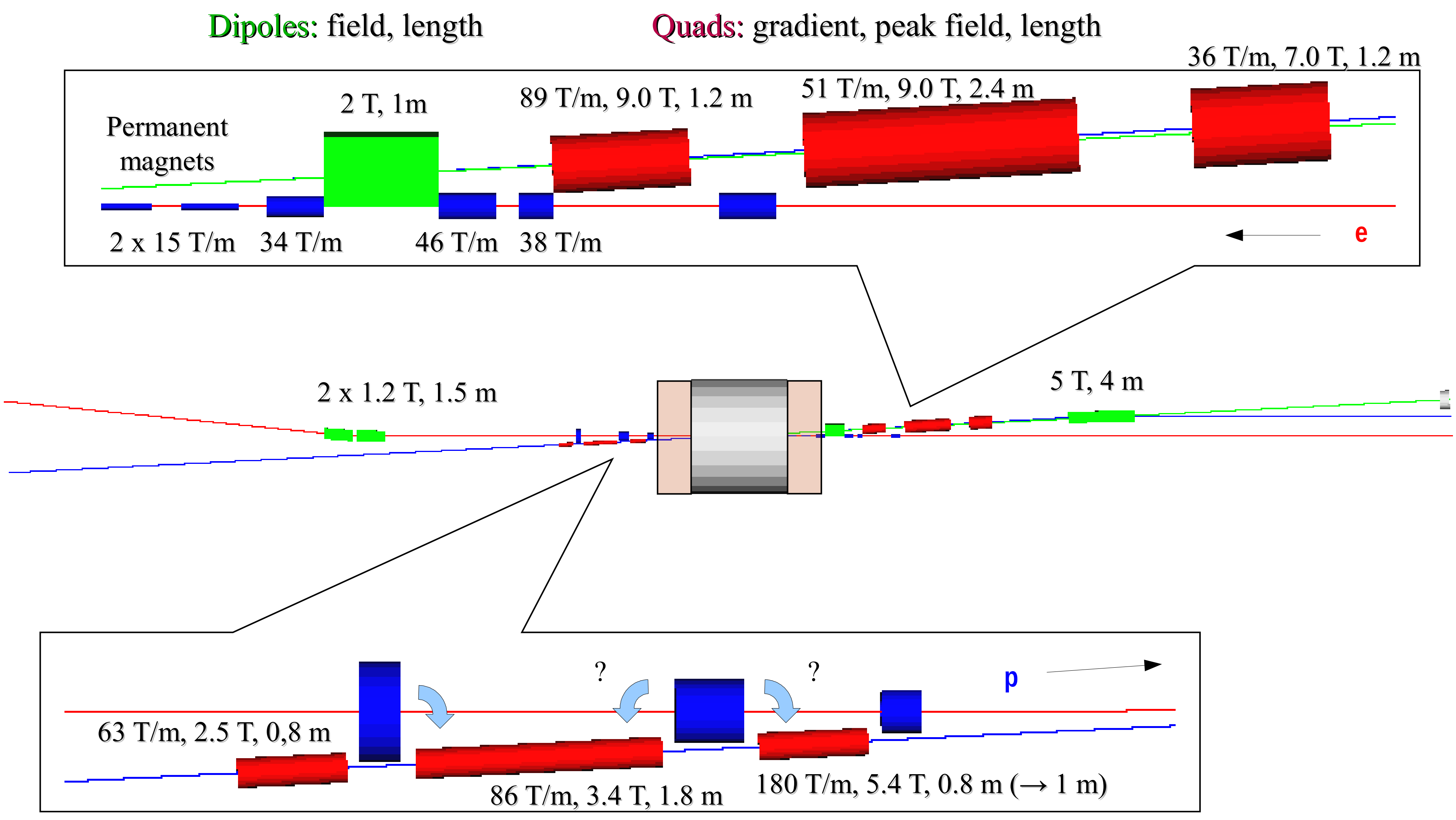
Small-angle ion detection – summary

- *Neutron* detection in a 25 mrad cone ***down to zero degrees***
- Excellent acceptance for ***all ion fragments***
- *Recoil baryon* acceptance:
  - up to 99.5% of beam energy for *all angles*
  - down to 2-3 mrad for *all momenta*
- Momentum *resolution* $< 3 \times 10^{-4}$
  - limited by intrinsic beam momentum spread



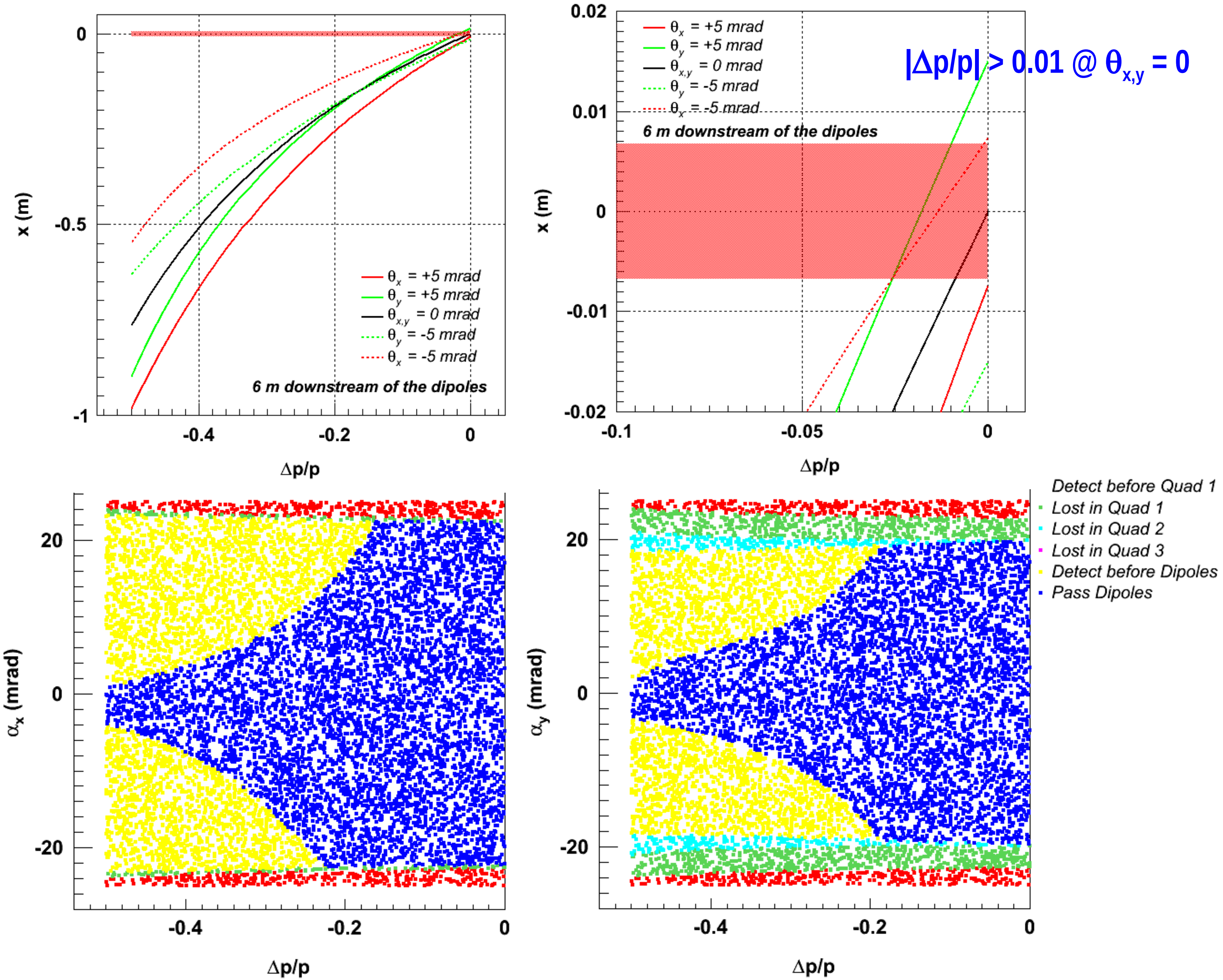
- 100 GeV maximum ion energy allows using large-aperture magnets with ***achievable field strengths***

IR magnets



- In the next, simplified version of the low-Q^2 tagger, ion and electron quads will use common cryostats.

Low-Q^2 lepton tagger



Summary

The MEIC

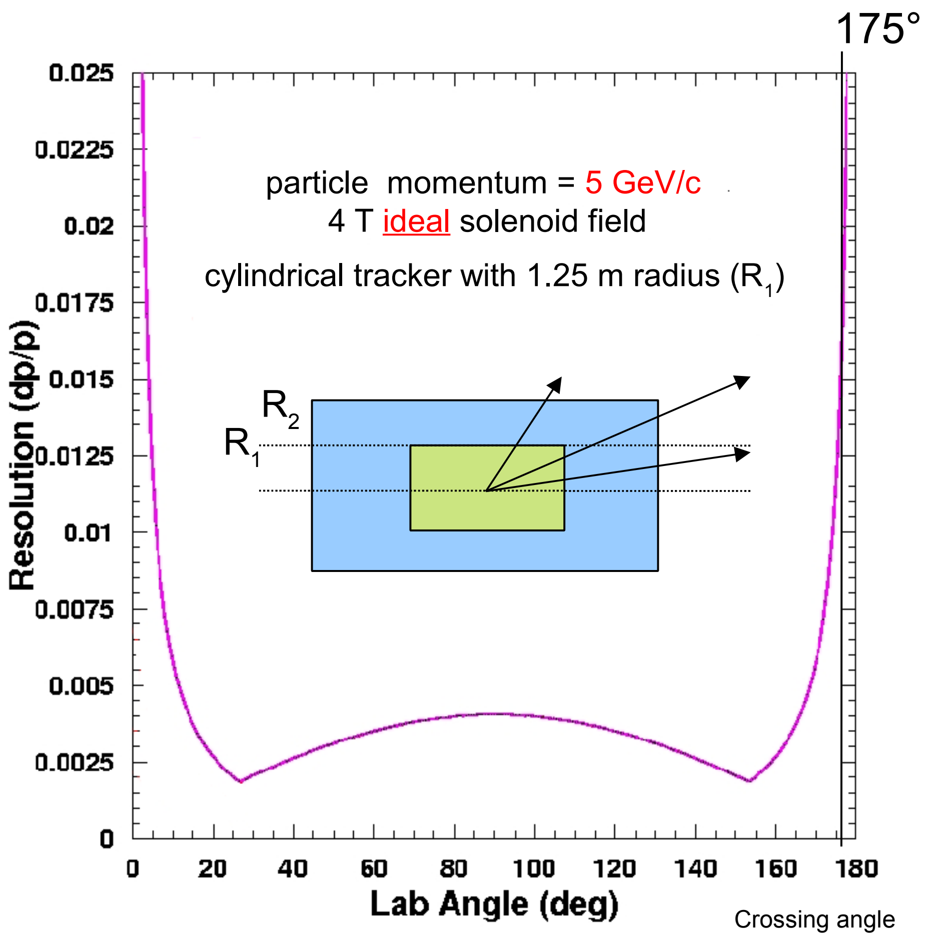
- Several detectors can be run in parallel
- Detector integration is a key part of the design process

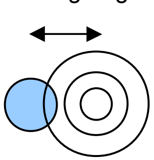
The full-acceptance detector

- Forward hadron detection in three stages
- Low-Q^2 lepton tagger
- Excellent performance can be achieved with state-of-the-art magnets
  - Investigating further simplifications of magnets
  - If needed, the design can be pushed to even better acceptances and resolutions
- Different detector technologies could be optimal in different places

Backup

Tracking: momentum resolution in a solenoid field

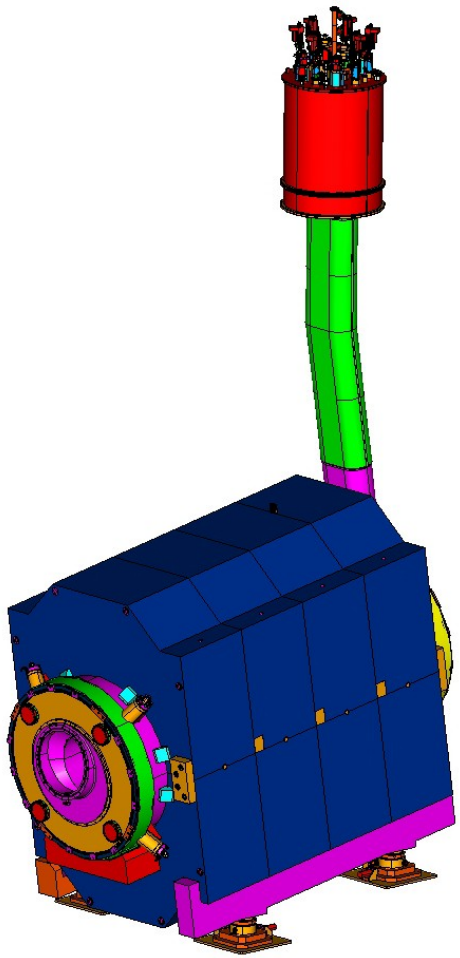




$$\Delta p/p \sim \sigma p / BR^2$$

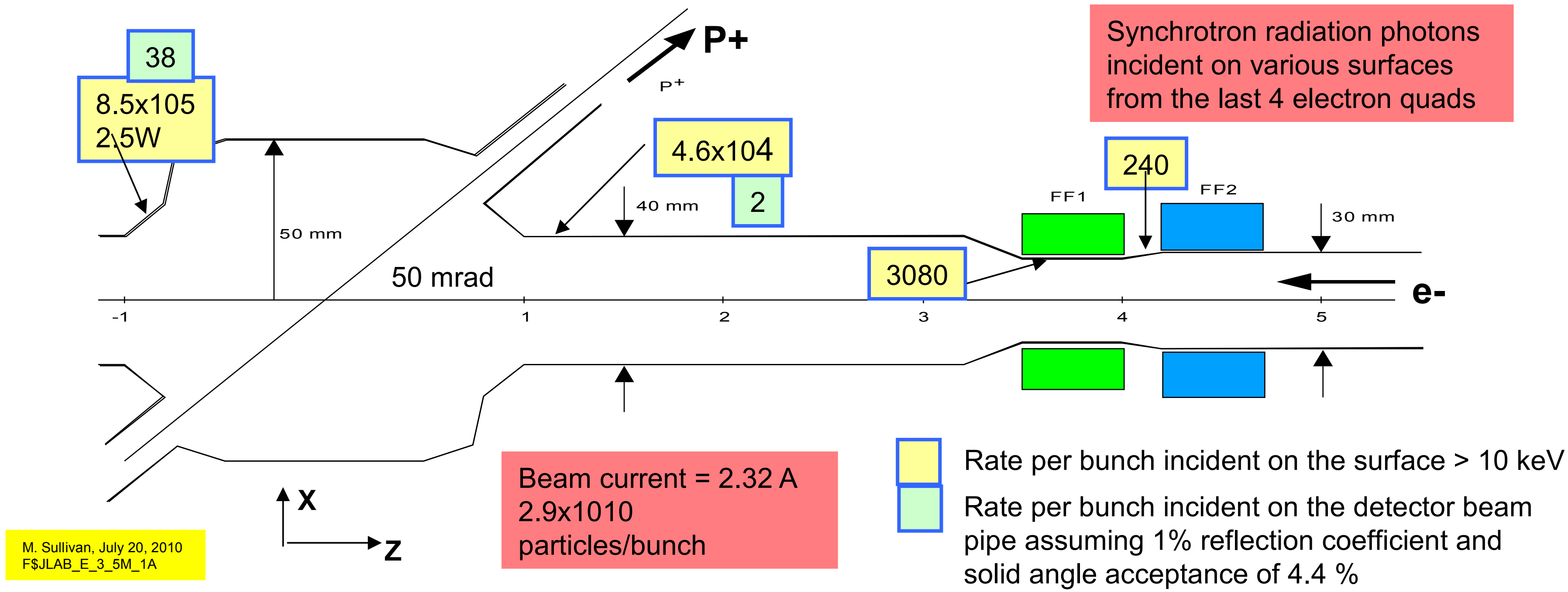
- Tracker (not magnet!) radius R is important at central rapidities
- Only solenoid field B matters at forward rapidities
- A 2 Tm dipole covering 3-5° can eliminate divergence at small angles
- A beam crossing angle moves the region of poor resolution away from the ion beam center line.
  - 2D problem!

Large Hall C dipole can serve as template



- 3.86 Tesla Cosine(Θ)dipole
- 60 cm warm bore
- 2.85 M EFL
- 11.2 TM Integral B.dL
- 10 % TEST margin
- 13.7 MJ stored Energy
- 4800 A/cm^2

Synchrotron radiation at IR



- Beam related detector backgrounds must be carefully analyzed and mitigation schemes developed that allow the detector to pull out the physics
  - Electron beams: controlling synchrotron radiation backgrounds and lost beam particles
  - Ion beams: controlling the lost beam particles
- Initial look at synchrotron radiation indicates that this background should not be a problem
- The new MEIC design, ion beam will be bent for crab crossing, minimizing SR in IR
- Beam stay-clear: 12 sigma

M. Sullivan

Backgrounds and detector placement

Random hadronic background

- Dominated by interaction of beam ions with residual gas in beam pipe between arc and IP

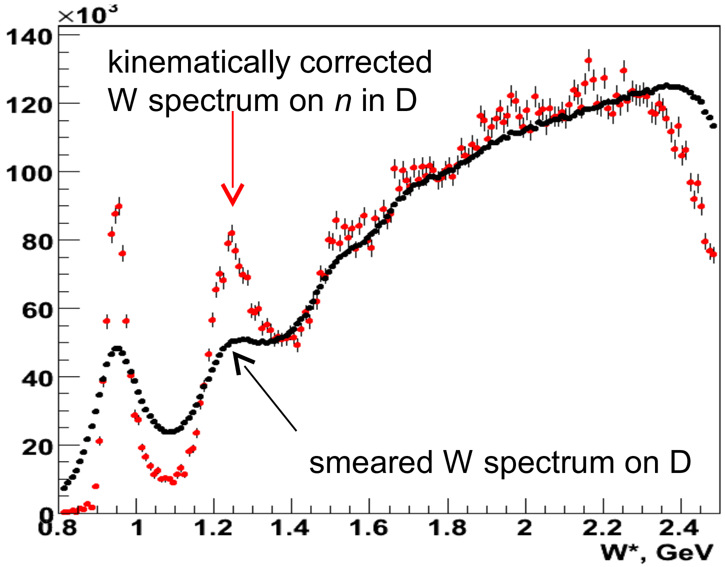
Comparison of MEIC (at s = 4,000) and HERA (at s = 100,000)

- Distance from ion exit arc to detector: 50 m / 120 m = 0.4
- Average hadron multiplicity: $(4000 / 100000)^{1/4} = 0.4$
- p-p cross section (fixed target): σ(90 GeV) / σ(920 GeV) = 0.7
- At the same ion current and vacuum, MEIC background should be about 10% of HERA
  - Can run higher ion currents (0.1 A at HERA)
  - Good vacuum is easier to maintain in a shorter section of the ring

Backgrounds do not seem to be a major problem for the MEIC

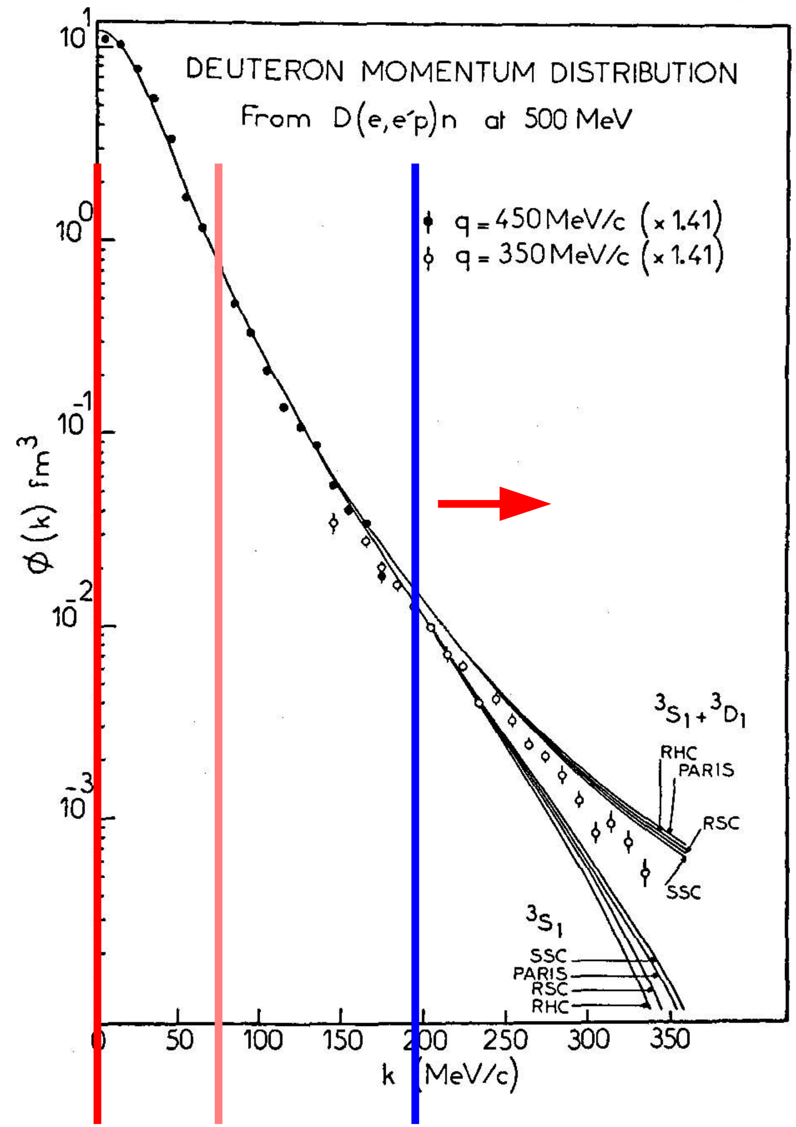
- Placing high-luminosity detectors closer to ion exit arc helps with both background types
- Signal-to-background will be considerably better at the MEIC than HERA
  - MEIC luminosity is more than 100 times higher (depending on kinematics)

Spectator tagging



CLAS BoNuS data with tagged spectators

- In fixed-target experiments, scattering on *bound neutrons* is complicated
  - Fermi motion, nuclear effects
  - Low-momentum spectators
- The MEIC allows easy tagging of *spectators* and *all nuclear fragments*

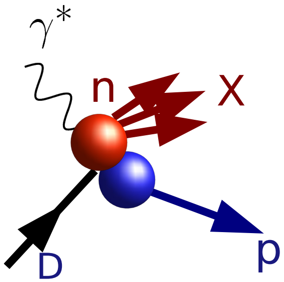


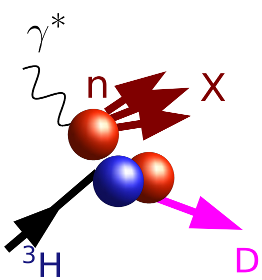
MEIC CLAS + BoNuS CLAS

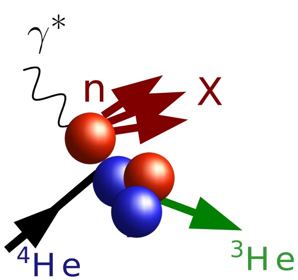
Spectator tagging

Quasi-free neutron

target	spect.
D	p
^{3}H	D
^{4}He	^{3}He

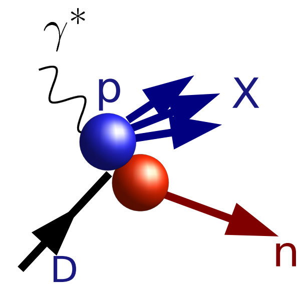


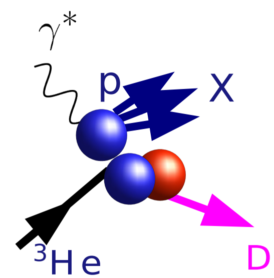


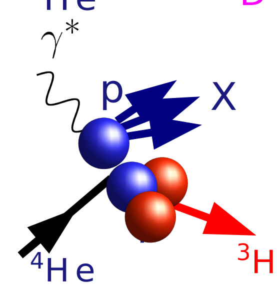


(Quasi)-free proton

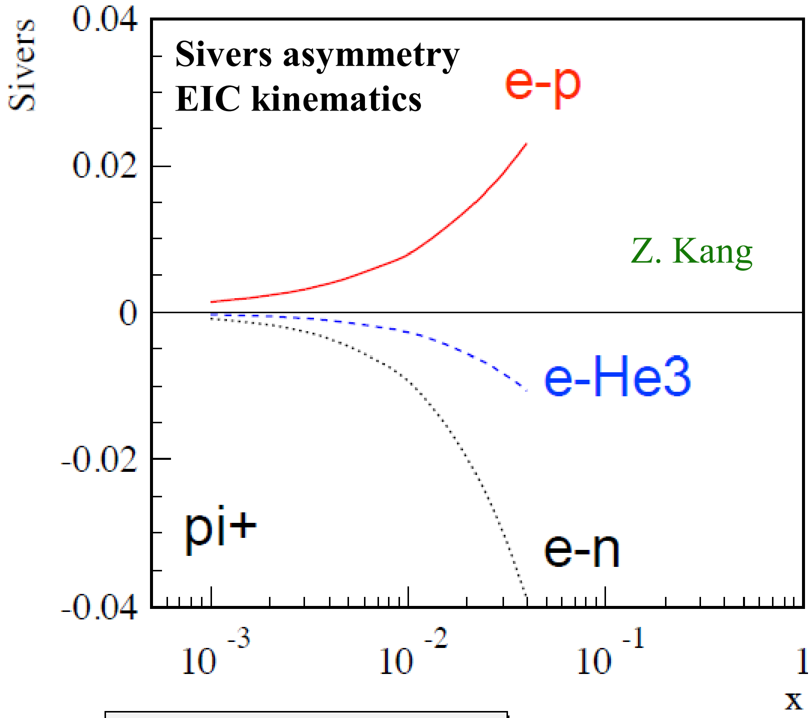
target	spect.
p	
D	n
^{3}He	D
^{4}He	^{3}H

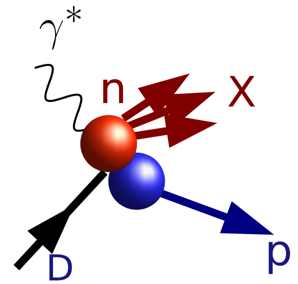




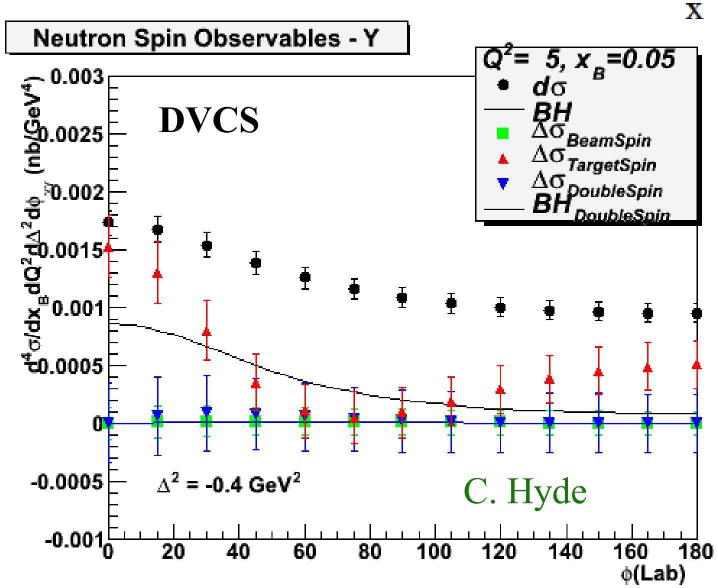


Spectator tagging – polarized deuterium





- MEIC will provide longitudinal and *transverse* polarization for d, ^{3}He, and other light ions



- Polarized *neutrons* are important for probing d-quarks through SIDIS

- Exlusive reactions like DVCS greatly benefit from polarized *neutron* “targets“
  - *c.f.* Hall A and B programs